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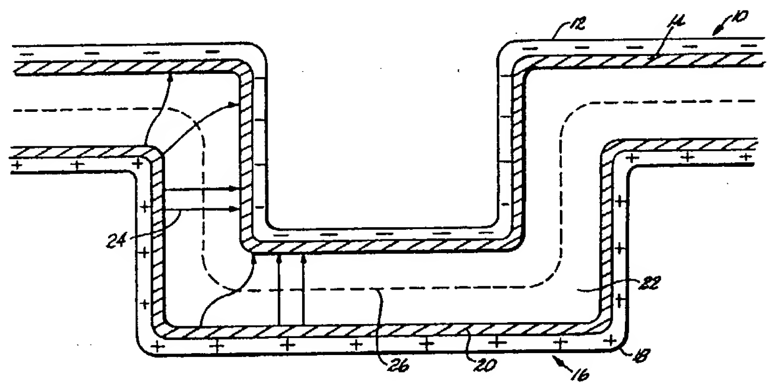

(57) Abstract

The present invention enables nuclear fusion of deuterons and lithons. A crystalline lattice (14) having octahedral interstitial sites aligned with an electrical field (24) is exposed on a first surface to a electrolytic solution of heavy water and lithium deuteroxide contained in a channel (22). Deuterium and lithium atoms from the electrolyte are absorbed into the crystalline structure where their electrons are stripped to produce deuterons and lithons, the latter retaining two electrons. Under the influence of the electric field, deuterons tunnel through the lattice and collect in interstitial sites to provide a palladium deuteride lattice (the β phase of palladium). A barrier, which may comprise an electrode (12) on which the crystalline lattice is deposited, is introduced which terminates the lattice perpendicular to the electric field to preclude further tunneling or diffusion of the deuterons from the interstitial sites adjacent the barrier. Heating of the electrolytic solution enhances the overlap of the energies of the diffusing particles with transmission resonance energy levels specific to the metal deuteride lattice and the particles diffusing through it. This promotes the diffusion of deuterons and lithons from the electrolyte into the lattice increasing the probability of fusion reactions between diffusing particles and the deuterons already in the lattice interstitial sites. Heat generated from the fusion reactions is extracted from the crystalline lattice and employed for power generation.

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METHOD AND APPARATUS FOR ENERGY PRODUCTION USING COLD NUCLEAR FUSION WITH A LITHIUM DEUTEROXIDE ELECTROLYTE

Cross-Reference to Related Applications

This is a continuation-in-part of prior U.S. Patent Application Serial Number 07/352,853, filed on May 15, 1989, in which a method and apparatus employing a crystalline palladium lattice for the production of energy using cold nuclear fusion is described in detail and incorporated herein by reference.

Field of the Invention

The present invention relates generally to production of power through the use of a steam turbine system receiving heat energy from a nuclear fusion reactor. More particularly, the invention provides a crystalline/palladium lattice reactor aligned in an electric field to receive deuterons into interstitial lattice sites from a deuterium source. The crystalline lattice is blocked perpendicular to the electric field in the lattice at a given depth preventing migration of deuterons out of the lattice. The crystalline lattice is immersed in a heavy water electrolyte solution containing lithium deuteroxide (LiOD). A heater maintains the electrolyte solution at an elevated temperature to increase the number of transmission resonance levels available for deuteron and lithium diffusion in the

lattice. Use of a high purity of Li^6 isotopes in the lithium deuteroxide enhances the reactor by reducing the probability of tritium production. Heat energy generated in the fusion is conductively transferred to a liquid coolant system and steam driven turbines for power generation.

Background of the Invention

Basic concepts for the generation of energy through nuclear fusion have centered on the so-called "hot" fusion approach. In "hot" fusion, deuterium atoms are forced together under great pressure and temperature sufficient to provide energy to overcome the Coulomb repulsion force and drive together the nuclei of the deuterium atoms to fuse. The result is nuclear fusion to produce an He^3 nucleus plus a neutron or a tritium nucleus plus a proton. Temperatures of 10^8 degrees K are required to provide sufficient energy to overcome the Coulomb barrier of the deuterons.

In a palladium lattice loaded with deuterons, a β phase of palladium is produced which may significantly increase the probability for nuclear reactions between deuterons diffusing through the lattice and the deuterons fixed in the lattice producing the β phase. It has been suggested by L. Turner in his letter to the editor published in Physics Today, 1989, pp. 140-141, that cold fusion may involve transmission resonances for deuterons diffusing through a periodic array of wells formed by the Coulomb barriers of the deuterons sitting at the interstitial sites. The resonance condition of

$$\int \kappa(x)\ dx = (n + 1/2)\ \pi$$

will provide a transmission coefficient of unity if satisfied by the wave number of the particle crossing the potential well between two neighboring barriers where $\kappa(x)$

is the wave number of the diffusing particle. A transmission resonance condition may be hypothesized as

$$(2n + 1)\ \lambda/4 = L$$

where n = 0, 1, 2 . . . .. λ is the de Broglie wavelength of the diffusing deuteron and L is the width of the well in the array. Electron screening of the deuterons by the palladium lattice will make the wells shallower than normal. Transmission will, therefore, occur for a diffusing deuteron whenever an odd number of quarter wavelengths of the deBroglie waves fit into the well width. Bohm has noted in <u>Quantum Theory</u>, Prentice-Hall, Inc., Inglewood Cliffs, New Jersey, 1951, p. 287, that "it is especially interesting that although a single high and thick barrier has a very small transmissivity, two such barriers in a row can be completely transparent for certain wavelengths. This barrier can be understood only in terms of the wave-like aspects of matter. The high transmissivity arises because, for certain wavelengths, the reflected waves from inside interfere destructively with those from outside so that only a transmitted wave remains."

As also shown by Bohm, the resonance condition also expresses the condition for existence of metastable or virtual states associated with wells having barriers. These states are unbounded and have a relative long lifetime due to the fact that deBroglie waves associated with the deuterons reflect back and forth in the well many times before the barrier is penetrated. The energies of these states may be found by combining the transmission resonance condition equation with the following well known relations:

$$E = p^2/2m \text{ and } \lambda = h/p,$$

where p is the momentum of the diffusing deuteron and m is its mass. Combining these equations yields the metastable state energies:

$$E_n = (2n + 1)^2 h^2/32m L^2.$$

Since these energies are based on the resonance condition to achieve transmission, these are also the energies for the transmission resonances.

If occupation of a metastable state is proportional to the Boltzmann factor:

$$\exp(-E_n/kT),$$

where k is the Boltzmann's constant and T is the temperature in Kelvin, the energies may be expressed in terms of temperatures T_n,

$$E_n = kT_n.$$

The Boltzmann factor may then be rewritten:

$$\exp(-T_n/T).$$

Substituting for the energy E_n, we find

$$T_n = (2n + 1)^2 h^2/32mkL^2.$$

This equation indicates the temperature relationship for resonance levels associated with the widths, L, of the wells in the array produced by the lattice as previously described.

An apparatus designed by Pons and Fleischmann has been reported in an article (see Fleischmann, M. and Pons, S., "Electro-chemically Induced Nuclear Fusion of Deuterium", submitted to Journal of Analytical Chemistry, March 20, 1989). The apparatus which was employed to

obtain the fusion reported in this paper was embodied in several forms. In a first embodiment, a palladium rod cathode and an encircling helical platinum anode were inserted in a heavy water (D_2O) electrolytic solution connected with a potential providing a maximum current density of approximately 512 mA/cm^2. In an alternative configuration, a rectangular palladium sheet cathode was surrounded by a platinum sheet anode and operated in the heavy water electrolyte with current densities of approximately 1.6 mA/cm^2. With both configurations, evidence of nuclear fusion was reported. However, methods and apparatus to obtain consistent power generation with controllability of the fusion reaction and necessary reliability are unknown.

Nuclear effects have also been noted by H. O. Menlove, M. M. Fowler, E. Garcia, A. Mayer, M. C. Miller, R. R. Ryan, and S. E. Jones, as noted in a presentation to the Workshop on Cold Fusion Phenomena, May 23 through 25, Santa Fe, New Mexico, entitled "The Measurement of Neutron Emissions from Ti + D_2 Gas". Neutron emissions were noted from titanium shavings pressurized with D_2 gas cooled to liquid nitrogen temperature and warmed to 243 K. Similar nuclear effects were seen in the Cassacia experiment reported by A. DeNinno, et al., in a presentation at the Workshop on Cold Fusion Phenomenon, May 23 through 25, Santa Fe, New Mexico, entitled "Neutron Emission from a Titanium Deuterium System", in which titanium blades were heated at 1,273 K in the presence of 0.1 mbar of D_2 gas, followed by lowering of the temperature to 773 K at 20 mbar D_2. Neutron emission was observed after reheating of the sample to 1,273 K. Again, however, methods and apparatus to obtain consistent power generation with controllability of the reaction present were not disclosed.

Summary of the Invention

The present invention provides a method and apparatus for obtaining heat energy from cold fusion. A palladium crystalline lattice provides a containment structure for deuterons in the octagonal interstitial sites of the face centered cubic structure. Deuterons with sufficient energy will migrate through a uniform palladium lattice by tunneling through the covalent bond barriers of the lattice. By alignment of an electric field with the <1,1,0> direction of the palladium lattice diffusion of the deuterons through the lattice is enhanced. To preclude diffusing particles from transitioning completely through the lattice, a means for blocking further tunneling is provided.

In a presently preferred embodiment, the palladium lattice is structured as a plurality of single crystal rods with the <1,1,0> direction of the individual lattice sites in the rods perpendicular to a first surface of the crystal. The first surface of the crystal is exposed to a source of deuterium atoms, such as a heavy water electrolyte solution, to provide a source of deuterons. The blocking member interfaces the crystalline lattice on another surface of the crystal perpendicular to the electric field to prevent tunneling of the deuterons completely through the crystal. Preferably the blocking member is a metallic structural member. The combination of the palladium crystal and the metallic member may operate as a cathode in an electrolytic cell.

An electrolytic solution containing lithium deuteroxide (LiOD) to provide lithium ions (lithons) and deuterium ions (deuterons) is employed in the cell. Deuterons diffusing into the palladium lattice create a β phase in the palladium which allows enhanced transmission of lithons and deuterons into the palladium deuteride lattice. The lithons and deuterons react in the lattice in a cold fusion process producing heat energy.

By employing high purity Li^6 isotopes in the lithium deuteroxide electrolyte, production of tritium is avoided thereby providing a "clean" reactor.

Configuration of the cathode as a structural dividing member allows containment of the electrolytic solution on the crystal surface of the cathode with circulation of a coolant fluid on the opposite side of the cathode to transport away heat generated by the fusion process in the lattice. A complementary anode structure of appropriate materials provides a second wall for the electrolyte container. Sealing between the edges of the electrodes with appropriate nonconductive material, such as quartz, completes the electrolyte container.

A heater is provided for the electrolytic solution to elevate the temperature for enhancement of transmission of the lithons and deuterons into the lattice by making more transmission levels in the palladium deuteride lattice available. Initiation of the fusion reaction is assisted by elevating the temperature of the electrolyte after loading of the palladium lattice with deuterons to achieve a β phase.

The potential applied across the electrodes is defined incrementally in magnitude by the desired transmission wavelength of the lithons and deuterons. The rate of the fusion process can be controlled by current density within the electrolytic cell. A larger forward current will increase power by accelerating tunneling of the lithons and deuterons in the lattice, while a reverse current will reduce tunneling in the lattice, shutting down the fusion reaction.

Brief Description of the Drawings

The preferred embodiment of the invention is shown in the drawings.

FIG. 1 is a top cross-sectional view of the electrolytic cell;

FIG. 2 is a pictorial representation of the palladium lattice.

FIG. 3 is a pictorial sectional view of the elements of the electrolytic cell;

FIG. 4 is a pictorial schematic diagram of the reactor core;

FIG. 5 is a schematic diagram of the reactor power plant;

FIG. 6 is a side cross-sectional view of one embodiment of the electrodes of the electrolytic cell employing a plurality of rods of palladium crystal;

FIG. 7 is a representation of the resonant transmission temperature levels for a PdD lattice;

FIG. 8 is a graph of the dimensionless power factor for the palladium deuteride lattice; and,

FIG. 9 is a graph of the temperature rate of change of the power factor.

Detailed Description

Referring to FIG. 1, two electrodes are shown. The first electrode 10 comprises a metallic structural member 12 with a palladium cladding 14. The structural member is configured in a corrugated pattern having multiple parallel channels for structural support and fluid cooling as will be described in greater detail subsequently. A second electrode 16 comprises a structural metallic member 18 with a cladding 20 of platinum or other nonreactive metal. The second electrode has a complementary shape to the first electrode and is mounted in spaced relation to the first electrode, creating a contained channel 22 between the two electrodes. This channel contains an electrolytic solution with purified heavy water (D_2O) and lithium deuteroxide (LiOD), or other metal deuteroxide which will be described in greater detail subsequently. A purity of 99.5% D_2O for the water in the electrolytic solution is preferred. Application of an electric potential across the two electrodes creates an electric field represented by field lines 24. The field will be perpendicular to the surface of each electrode. As is typical of electrolytic cells, deuterium gas will be evolved at the surface of the cathode, while oxygen gas will evolve at the surface of the anode. A spun quartz fiber screen 26, which bisects the channel between the electrodes, is employed to prevent mixing of the deuterium and oxygen gases as they rise to the top of the channel where they are vented into separate collection reservoirs, as will be subsequently described.

The palladium cladding on the cathode is arranged to provide a crystalline lattice of palladium having a significant plurality of the individual cells of the lattice each oriented with a <1,1,0> direction parallel to the electric field at the electrode surface as well as the interior of the lattice. This condition is achieved by methods to be described in greater detail subsequently. As shown in FIG. 2 for a face centered cubic lattice 210,

the individual atoms 212 are joined by covalent bonds 214. The direction of view in FIG. 2 is along a <1,1,0> direction of the lattice. An electric field perpendicular to the electrode surface as shown in FIG. 1 is therefore perpendicular to the interstitial sites in each lattice cell through the associated covalent bonds. The arrangement of atoms in the lattice provides an octahedral interstitial site cornered by the atoms and bounded on each side by covalent bonds. Deuterium atoms adsorbed on the surface of the crystal lattice are drawn into the interior of the lattice by the electric field. As the deuterium atoms enter the electrode's interior they are stripped of their electrons. These electrons move into the Palladum conduction band and become delocalized from the deuterium nucleus, or deuteron. The deuteron is then acted on by the electric field and drawn through the lattice until a physical barrier is encountered which cannot be tunneled through or diffused around by the deuteron.

The stripping of the electron from the deuterium atom in effect transforms a fermion (the deuterium atom) into a boson (the deuteron).

The potential between the electrodes is established to provide an electric field for loading of the lattice having a magnitude to excite the deuteron wavelength for transitioning through the covalent bonds of the crystalline lattice. For this effect the deuteron wavelength is described by the equation: $(\lambda)=4L/n$, where L is the distance across the octahedral sites in the lattice (approximately two Angstroms in palladium), and n is an odd integer. The addition of an AC ripple signal may be employed to tune the field for appropriate deuteron wavelength.

The barrier is placed perpendicular to the electric field, which is the preferred direction of migration of the deuterons. In some configurations, the barrier may interface with the crystal on more than one plane to block

deuterons driven by components of the electric field parallel to more than one of the <1,1,0> directions of the lattice.

The electric field in the electrode itself is determined in part by the physical connection of the electrode to the electrical potential. The electrical field in the palladium cladding in the preferred embodiment is maintained substantially perpendicular to the surface of the cladding by the use of a metallic support having high conductivity and significant depth dimension with respect to the cladding. In addition, as the deuterium atoms diffuse into the palladium cladding, the resistance of the cladding increases. The net effects of the physical geometry of the support and the increased resistance of the palladium cladding is the displacement into the metallic support of the majority of current flow to the potential. Consequently, the electric field in the palladium cladding remains essentially perpendicular to the surface of the electrode and the cladding.

If enhancement of the direction of the electric field in the cladding is required, strips of insulator may be added to the surface of the palladium cladding, extending into the cladding perpendicular to the surface and to the direction of net current flow to the potential. Channeling of current perpendicular to the surface accomplished by the insulating strips enhances the field perpendicular to the surface.

An embodiment of this form is shown in FIG. 6 in which long single crystals 610 are laminated between insulating strips 612 onto a polycrystalline cladding 614. The single crystals have a <1,1,0> axis parallel to the electric field which is forced to remain in a direction perpendicular to the electrode surface all the way through the single crystal.

These long single crystals may be grown using a floating zone electron beam method. Polycrystalline rods of 4 - 5 mm in diameter are bombarded with an electron

beam in a vacuum environment of 10^{-5} to 10^{-6} Torr. The beam melts a region of the rod approximately equal to the diameter in length. The heated section of the rod recrystallizes as a single crystal. The rod is then advanced and a new length bombarded by the beam similar to a zone refining process. Details of the process may be found in Pamplin, B.R., Crystal Growth, Pergamon Press (1975) PP 140 -142. Impurities are evaporated during this process, further enhancing the crystal.

The polycrystalline cladding in the embodiment shown in FIG. 6 is silver or other nonreactive metal having a higher thermal conductivity than palladium and a smaller crystalline structure to provide a deuteron diffusion barrier.

In each of the embodiments described, the structural member provides the electrical contact in addition to a barrier to diffusion and tunneling of the deuterons in the palladium cladding perpendicular to the surface of the electrode. As previously described, the electric field direction in the cladding layer is substantially perpendicular to the surface of the layer, resulting in the structural support being perpendicular to the field to provide an effective barrier for the deuterons.

Referring now to FIG. 3 the preferred configuration of the electrodes is suitable to provide a self-contained electrolytic cell. The corrugated shape of the cathode 10 and complementary shape of the anode 16 when placed in spaced relation provide two sides of an enclosure for the heavy water electrolyte of the cell. Sealing at the peripheral extremities of the electrodes may be accomplished by a insulating quartz cap 310 employing quartz to metal seals 312 at the cathode and anode. Similar insulating quartz caps may be employed at the upper and lower boundaries of the electrodes with appropriate connections for introducing the electrolytes and withdrawing the evolved gases.

As shown schematically in FIG. 4 multiple cells 410 may be placed in a common pressure vessel 412. The electrolyte is supplied to each of the cells through connection 414. Deuterium and oxygen gas evolved at the surfaces of the electrodes in each cell are scavenged through connections 416 and 418, respectively. As previously described with respect to FIG. 1, a spun quartz fiber screen or other appropriate device may be employed to prevent mixing of the deuterium and oxygen gases in the electrolytic cells.

Coolant is introduced to the pressure vessel at connection 420 and circulated through the channels formed by the electrodes external to the electrolytic cell. Withdrawal of the circulating coolant is accomplished at connection 422. In the embodiment shown high purity ordinary water (H_2O) is used as the coolant. Appropriate corrosion protection steps for the structural members of the electrodes exposed to the coolant must be employed to prevent degradation of the electrodes.

The circulating coolant provides the heat exchange medium for withdrawing energy from the reactor which is created by fusion in the palladium reactor lattices of the cathodes in the electrolytic cells. An embodiment employing standard steam plant operating parameters provides an operating temperature of 650°C. This results a factor of approximately two for safety margin to the melting temperatures of materials employed in the electrolytic cells and reactor pressure vessels (steel 1600°C, nickel 1455°C, palladium 1549°C, platinum 1773°C, copper 1100°C).

Operation at 650°C requires pressurization above 2200psi to prevent boiling in the system. The coolant loop in the reactor and the heavy water electrolyte are therefore maintained above 2200psi.

FIG. 5 provides a schematic for an embodiment of a power generation system employing the reactor of FIG. 4 and a dual coolant loop power generation system. A heavy

water electrolyte tank 510 stores the electrolyte which is pumped to the electrolytic cells through a first feed pump 512 to the pressure vessel. The evolved oxygen and deuterium gas from the electrolytic cells are stored in tanks 514 and 516, respectively. Liquefaction of the gases may be employed to reduce storage volume. The primary coolant loop provides cooling water through a second pump 520 to the pressure vessel. Coolant exiting the pressure vessel is routed through a heat exchanger 522 and returned to the pump 520. A secondary coolant loop employing water or other appropriate coolant receives heat in the heat exchanger to generate power in the turbine 524 after which it is condensed in condenser 526 and returned to the heat exchanger by a third pump 528.

The present invention also controls the temperature of the electrolytic solution. The temperature relationship

$$T_n=(2n+1)^2h^2/32mkL^2$$

provides a basis for hypothesizing the transmission resonance level spectrum for a palladium deuteride (PdD) lattice. From the experimental evidence of Pons and Fleischmann previously described, transmission resonance is present at room temperature (293K). By solving for the well width for T_n=293k we find

$$L_n=(2n+1)(0.349Å)(243K/293K)^{1/2}$$
$$=(2n+1)(0.318Å)$$

Therefore, for integers 0,1,2,3,4, etc. the following well widths are defined

0.318Å, 0.953Å, 1.59Å, 2.22Å, 2.86Å, etc.

The lattice parameter for Pd in the α phase is well known to be 3.89Å. It is also known that the lattice undergoes

a uniform 11% expansion to reach the β phase. Therefore, the new lattice parameter is given by 3.89Å x $(1.11)^{1/3}$. The separation of two deuterons residing at neighboring octahedral interstitial sites is the value of the lattice parameter divided by $(2)^{1/2}$ or 2.85Å.

Selecting the width of the a well formed by the ascending Coulomb barriers of neighboring deuterons in the lattice as 2.86Å a temperature level scheme for transmission resonance levels may be obtained for a deuterium loaded β phase palladium lattice with deuterons as the diffusing particles (diffusons).

$$T_n=(2n+1)^2(27K)(1.047Å/2.86Å)^2$$
$$=(2n+1)^2(3.62K)$$

FIG. 7 portrays this level scheme.

A temperature width, ΔT_n, is present at each level. ΔT_n is associated with the variation in the well width due to thermal vibration. This may be characterized as phonon exchange between the deuterons responsible for the Coulomb barrier wells and the metal lattice. This variation, ΔL, in the well width due to vibration from the level T_n may be estimated by

$$(1/2)m\,\omega^2(\Delta L)^2 = (1/2)kT$$

therefore,

$$\Delta L = (kT/m\,\omega^2)^{1/2}.$$

Then,

$$\Delta T_n = 2(\Delta L/L)T_n.$$

These level widths provide transmission bands for propagation of the deuterons in the lattice. Transitions via phonon exchange with the lattice would become

significant whenever the thermal energy kT associated with an "average" phonon becomes of the order of kT_n, i.e. when $T=T_n$. Neutron emissions may be created by transitions of diffusing deuterons between levels. The burst nature of these emissions may associated with the boson nature of neutrons since the symmetric wave function gives bosons the tendency to be "gregarious".

The deuterium reactions in the lattice may be

$$D + D \rightarrow T + p$$

$$D + D \rightarrow He^3 + n$$

The following nuclear reactions may also be catalyzed from the system using the LiOD and heavy water electrolyte via the transmission resonances within the lattice:

$$T + D \rightarrow He^4 + n$$

$$He^3 + D \rightarrow He^4 + p$$

$$Li^6 + D \rightarrow 2He^4 + 22.4 \text{ MeV}$$

Reactions of Li^7 to produce tritium may also be present.

The Li^6 - on - a - deuteron reaction to produce He^4 is hypothesized as the primary energy producing reaction in the present invention. Again solving for the well width in the lattice, now for Li^6 diffusons in a PdD lattice, we see

$$L_n = (2n+1)(0.1838Å)$$

This generates widths of

0.18Å, 0.55Å, 0.92Å, 1.29Å, 1.65Å,

2.02Å, 2.39Å, 2.76Å, 3.12Å, etc.

Again employing the width closest to that of 2.85Å characteristic of the PdD lattice, 2.76Å, we obtain

$$T_n = (2n+1)^2(1.303K)$$

resulting in levels of

1.3K, 11.7K, 32.6K, 63.8K, 105.5K, 157.7K, 220.2K, 293.2K, 376.6K, etc.

For Li^7 diffusons within the PdD lattice we find

$$L_n = (2n+1)(0.1702Å)$$

resulting in

$$L = 2.89Å$$

leading to a result for the transmissions levels temperatures of

$$T_n = (2n+1)^2(1.0145K)$$

with transmission levels of

1.0K, 9.1K, 25.4K, 49.7K, 82.2K, 122.8K, 171.5K, 228.3K, 293.2K, 366.2K, etc.

The presence of a transmission resonance level at 293.2K (20C) or room temperature in the deuteron, Li^6, and Li^7 transmission level structures and numerous transition levels below room temperature supports the presence of heat producing reactions in a room temperature system. Increasing the temperature of the electrolytic solution shifts the Boltzmann distribution for the diffusons to higher energies. This gives more overlap with the higher

order (greater n) transmission levels, which also have more of a thermal width. This enhances the probability of transmission of the diffusons with a consequent enhancement for nuclear reactions.

The tunneling process ordinarily associated with a cold fusion reaction is sensitive to the mass of the tunneling particle. For example, R. Bush and R. Eagleton in "Cold Nuclear Fusion: A Hypothetical Model to Probe an Elusive Phenomenon", Journal of Fusion Energy, accepted for publication August 1989, show that the transmissivity for cold fusion not involving a metal lattice is given approximately by

$$T = \exp\{-\alpha(m/E)^{1/2}\}$$

where α is a constant, m is the mass of the tunneling particle, and E is the energy of the particle incident upon the Coulomb barrier. For particles of equal energy E, the probability for tunneling decreases strongly as the mass m increases. In contrast, cold Fusion within a metal lattice such as the palladium deuteride in the present invention can actually increase as mass increases. This is clear from the equation for the de Broglie wavelength of the diffusing particle

$$\lambda = h/(2mE)^{1/2}$$

since for particles of equal energy, E, λ is smallest for the particle of largest mass. The advantage of smaller λ is that there are more ways in which the transmission resonance condition can be satisfied. The formula for T_n specifying the resonant transmission levels also shows this, since mass m occurs in the denominator. Based on this, nuclear reactions in the PdD lattice involving Li^6 and Li^7 may predominate over those involving deuterons. (Additionally, Li^6 may predominate over Li^7 since the former are bosons while the latter are fermions.)

Similar calculations may be made for alternate metallic lattices such as titanium which may be used for electrode materials. Titanium deuteride as a lattice does not provide the large number of transmission resonance levels present in palladium deuteride for the same temperature with deuterons as the diffusons. However, structural or other considerations may make the use of a titanium lattice in the cathode desireable with an alternate diffuson.

Enhancement of the transmission resonance levels available for the deuterons is accomplished in the present invention by heating the electrolyte entering the reactor in a feed water heater 530 as shown in FIG.5. The heater is operated to achieve electrolyte temperatures of 500 to 600 C to provide the greatest number of transmission resonance levels for the deuterium and Li^6 in the electrolyte to be transmitted through the lattice.

Electrical resistance heating, fuel fired heat exchangers or other methods may be used for the feedwater heater. Recombination of the O_2 and D_2 gases produced by the cell may be used for the fuel heat source or as an energy supplement for the feedwater heater by returning the gases to the heater shown schematically by lines 532 and 534 in FIG. 5.

The use of high purity Li^6 for the LiOD in the electrolyte provides a "clean" reactor avoiding production of tritium from Li^7. An optimum electrolytic solution having .1 to .5 molar LiOD with a purity of 99.5% for Li^6 is used.

A power factor P(T) is used to compare the transmission aspects of the reactions in the present invention. P(T) is proportional to the total number of diffusing deuterons and therefore is equal to the number of deuterons in metastable states. The population of deuterons in the nth state is proportional to the Boltzmann factor therefore

$$P(T) = \Sigma \exp(-E_n/kT)$$
$$= \Sigma \exp(-T_n/T).$$

The value of P(T) increases with increasing temperature T due to the negative exponentials. A positive temperature coefficient for the cold fusion process is therefore present. A plot of the power factor for palladium deuteride is shown in FIG. 8.

SImilarly, if it is assumed that all other aspects such as nuclear cross-sections remain the same at different temperatures the rate of change of the power factor with temperature follows directly

$$dP/dT = T^{-2} [\Sigma T_n \exp(-T_n/T)].$$

A plot of dP/dT is shown in FIG. 9 for palladium deuteride.

The rate of change of the dimensionless power factor with temperature has an inverse square dependence upon the temperature. Similar calculations may be made for a Titanium deuteride lattice.

Near the surface of the electrode the diffusion of the deuterons (and other particles) in the lattice may be described in terms of the Maxwell velocity distribution for a temperature T.

$$dN(v)/dv = T^{-3/2} v^2 \exp(-mv^2/2kT)$$

where N is the number of diffusing particles with velocity v. A velocity v_n corresponding to a transmission resonance is given by

$$v_n = h/m\lambda$$

where the de Broglie wavelength λ satisfies the resonance condition. The number of diffusing deuterons having this velocity corresponding to a particular value of n is

proportional to the area under the curve of $dN(v)/dv$ versus v for the value $v=v_n$. This, of course, is zero. Therefore, it is the phonon exchange between the lattice and the deuterons whose Coulomb barriers form the wells, that results in a thermal width for the resonance transmission levels, thus providing candidate deuterons for transmission. The velocity width Δv_n corresponding to the ΔL is given by

$$\Delta v_n = 2\ \Delta L m v_n{}^2/h.$$

The relation of v_n to the nth order transmission resonance level is

$$m v_n{}^2/2 = kT_n.$$

Taking the thermal width into account for the transmission resonance velocity, the number of candidate deuterons for resonant transmission is now proportional to the area under the curve of $dN(v)/dv$ versus v between $v_n - (\Delta v_n)/2$ and $v_n + (\Delta v_n)/2$. This can be approximated by

$$\begin{aligned}\{[dN(v)/dv]_v\ \Delta v_n\} &\propto T^{-1}T_n{}^{3/2}\exp(-T_n/T)\\ &\propto T^{-3/2}T_n{}^{1/2}\ \Delta T_n \exp(-T_n/T)\end{aligned}$$

Since $\{[dN(v)/dv]_v\ \Delta v_n\}$has a maximum when $T = T_n$ setting the derivative with respect to the temperature T_n equal to zero will provide a maximum:

$$d/dT[T^{-1}T_n{}^{3/2}\exp(-T_n/T)] = 0$$

Solving this equation shows the maximum at

$$T_{max} = T_n.$$

This also corresponds to the most probable velocity for the Maxwell velocity distribution. This implies that

neutron bursts may be produced by deuterons with correlated velocities with the maximum of the velocity distribution corresponding to a transmission level, v_n.

This allows a power factor of

$$P(T) = T^{-1}\Sigma T_n^{3/2}\exp(-T_n/T)$$

for comparing powers at different temperatures for a particular lattice (e.g. PdD). Thus, for Li^6 lithons as diffusons in a PdD lattice it can be shown that the power yield would be three times a great at 600 K as at 293 K. Nuclear factors should enhance this.

As a second embodiment, the growth of dendrites or sintering of palladium grain crystals on the surface of the cathode is provided to enhance a surface reaction. In this embodiment, the structural support of the electrode is first clad with a thin film of polycrystalline palladium foil, or other conductive nonreactive material, by electroplating, vapor-deposition or other technique, and a layer of single crystal palladium grains is sintered to the surface of the palladium cladding. Annealing of the sintered grains is accomplished to create essentially a single crystal in each grain.

A temperature coefficient based on this power factor is also positive., and assuming other conditions to be the same, more power is yielded at higher temperatures. The Maxwell velocity distribution is shifted by increasing temperature for higher values of v thereby allowing more transmission levels, v_n, to make a significant contribution. The thermal width, ΔT_n, of a transmission level is proportional to both n and $T^{1/2}$.

The present invention provides opportunity for cold fusion by loading a metal deuteride lattice and providing diffusing particles, deuterons and lithons, with energies overlapping the transmission resonance levels defined by T_n. Loading of the lattice is enhanced by arrangement of the crystal lattice parallel to the electric field between

the electrodes and providing a barrier to prevent diffusion completely through the lattice as previously described. Loading of the lattice is accomplished with a current density of about 10 - 50 mA/cm^2 to create a β phase by loading deuterons in the interstitial sites in the lattice. Achieving stoichiometry of at least .7 in the reactive portion of the lattice is desirable in the loading.

Loading is conducted with the lattice and electrolyte at room temperature or lower. After loading is complete, the probability of fusion reaction is enhanced by increasing the electrolyte temperature using the feed water heater. "Bumping" of the current between the electrodes may be employed to assist in starting the resonant transmission of particles into the loaded lattice. The AC ripple previously described will be sufficient in most applications.

As previously described control of the fusion reaction in the individual cells is accomplished by varying the current density in the electrodes thereby controlling migration of deuterons and lithons through the lattice to the barrier points. Variation in the electrolyte temperature by increasing or decreasing heat input through the feed water heater is also employed to control the reaction.

Operation of the reactor will eventually "poison" the electrodes with He^4 in the lattice. Further, the lattice cites in which fusion has taken place and those surrounding will be damaged due to the production of heat. The electrodes in the reactor must then be refurbished or replaced.

In operation, application of electric potential to the reactor cells could be alternated for periodic intervals to allow annealing of the crystalline lattice or reformation of the crystal in the sites damaged by fusion by heating from adjacent cells to effectuate "self repair". If electrode annealing is too slow at 650 C

design of the operating temperature and pressure of the reactor may be correspondingly increased as required within limits imposed by the structural materials.

Reduction of pressure of the electrolyte in combination with heating will provide some limited removal of the He^4 in the lattice. It should be noted that removal of the reactor electrodes and recovery of the He^4 present will provide significant cost benefit.

As alternative embodiments to that described previously, the reactor lattice may be arranged on a symmetrical electrode such as a sphere or cube where all surfaces of the electrode exposed to the electrolyte are perpendicular to the electric field and the field inside the electrode is aligned essentially through the geometric centroid of the electrode. Those skilled in the art will recognize fabrication and electrical connection techniques such as an insulated probe electrically connected at the tip with the geometric centroid of the electrode to provide the potential to the electrode. This arrangement of all electric field lines radiating from the center of the electrode provides a self-induced "boundary" at the center of the electrode preventing the deuterons from exiting the electrode. Practical heat removal in this configuration may prove difficult.

It should further be noted that the reactor design of the present invention is compatible with the structural components of existing fission reactor designs. The fission cores in these reactors could be replaced with the cold fusion electrode systems of the present invention as a retro-fit significantly reducing capital cost for building such fusion reactors and providing a beneficial use for decommissioned fission reactors in providing clean power generation.

Having now described the invention in detail as required by the patent statutes, those skilled in the art will recognize potential modifications to the geometry and materials employed in the electrodes including the

crystalline lattices and possible power generating plant configurations without departing from the scope and intent of the invention as described in the following claims.

WHAT IS CLAIMED IS:

1. An apparatus for producing heat energy through cold fusion comprising:

a crystalline reactor lattice having octahedral interstitial sites defined by atoms of the lattice, and the atoms having parallel bonds on opposite sides of the octahedral sites;

a means for maintaining an electrolytic solution including heavy water and metal deuteroxide as a source of deuterons and metal ions for diffusing particles in communication with a surface of the crystalline reactor;

means for generating an electric field perpendicular to any pair of parallel bonds of a significant plurality of the interstitial sites, the electric field having a magnitude causing the average wavelength of the diffusing particles, between collisions, to be equal to a transmission resonance wavelength;

means for creating a boundary which blocks the lattice perpendicular to the electric field in the lattice at a location of lower electric potential than the surface of the crystalline reactor; and,

means for heating the electrolytic solution.

2. An apparatus as defined in claim 1 wherein the crystalline reactor lattice comprises a plurality of single metallic crystals of face centered cubic structure oriented in any <1,1,0> direction with respect to a surface of the crystal.

3. An apparatus as defined in claim 2 wherein the metallic crystal is palladium.

4. An apparatus as defined in claim 3 wherein the metal deuteroxide is lithium deuteroxide and the metal ions are lithons.

5. An apparatus as defined in claim 3 further comprising a structural member having a polycrystalline cladding to which the reactor lattice is bonded.

6. An apparatus as defined in claim 5 wherein the lattice comprises single crystal grains of palladium sintered to the polycrystalline cladding.

7. An apparatus as defined in claim 4 wherein the means for generating an electric field comprises:

a cathode, the reactor lattice being an integral portion of the cathode;

an anode immersed in the electrolytic solution, and,

an electric potential connected between the anode and cathode.

8. An apparatus as defined in claim 7 wherein the electric potential is adjustable.

9. An apparatus for producing heat energy from cold fusion of diffusing particles comprising:

an electric potential;

a heavy water and lithium deuteroxide electrolyte bath;

a first electrode connected to the potential and having at least one surface immersed in the bath;

a second electrode connected to the potential having at least one surface, substantially parallel to the surface of the first electrode at all points of tangency, said one surface immersed in the bath thereby completing the circuit and creating an electric field in the bath and the second electrode further having:

a metallic face centered cubic crystalline reactor lattice exposed at the surface of the second electrode, with a substantial plurality of octahedral

interstices of the lattice oriented with the <1,1,0> direction perpendicular to the surface,

a metallic boundary, perpendicular to the electric field in the second electrode, at which the lattice terminates thereby preventing further tunneling and diffusion by diffusing particles in a direction parallel to the electric field, and,

a means for controlling the temperature of the electrolyte.

10. An apparatus as defined in claim 9 wherein the lattice terminates at a metallic boundary on each surface not in contact with the electrolyte thereby preventing tunneling and diffusion by the deuterons from the lattice.

11. An apparatus as defined in claim 9 wherein the electric potential is controllable and reversible.

12. An apparatus as defined in claim 10 wherein the crystalline reactor lattice comprises a plurality of single crystals and the metallic boundary comprises a structural member connected to the electric potential and further comprising dielectric strips bonded intermediate the single crystals to form a laminated lattice, the dielectric strips perpendicular to a direction of primary current flow in the structural member.

13. An apparatus as defined in claim 9 wherein the electrolyte contains lithium deuteroxide having a 99.5% purity of Li^6.

14. An apparatus as defined in claim 13 wherein the molality of the lithium deuteroxide in the electrolyte is .1 to .5.

15. A method of producing power by fusion of diffusing particles with trapped particles in a lattice comprising the steps of

fabricating a reactor cell by the steps of

forming a plurality of single crystal palladium rods having a <1,1,0> direction perpendicular to the surface of the rods,

mounting the rods to a metallic structural member to form a first electrode,

placing a second electrode in parallel spaced relation to the first electrode,

sealing between the adjacent peripheral edges of the first and second electrodes, and,

introducing a heavy water and metal deuteroxide electrolyte between the electrodes as a source of deuterons and metal ions as diffusing particles,

circulating a coolant around the reactor cell,

applying an electric potential between the first and second electrode,

controlling the polarity and magnitude of the electric potential,

heating the electrolyte, and,

withdrawing heat energy from the coolant to generate power.

16. A method as defined in claim 15 wherein the metal deuteroxide used is lithium deuteroxide and the metal ions are lithons.

17. A method as defined in claim 15 wherein the heavy water in the electrolytic solution is 99.5% pure.

18. A method as defined in claim 15 further comprising the steps of:

installing a plurality of reactor cells in a pressure vessel, and,

alternately applying the electric potential to selected reactor cells to allow annealing of adjacent reactor cells.

19. A method as defined in claim 16 further comprising the step of reducing the pressure of the electrolyte during annealing of reactor cells to extract He^4 contaminant from the electrodes.

20. A method as defined in claim 15 further comprising the step of loading the palladium lattice with deuterons to a stoichiometry of between .7 and 1 prior to heating the electrolyte.

21. A method as defined in claim 20 further comprising the step of providing an AC ripple on the electrode potential to bump the current in initiating a resonant transmission of lithons and deuterons into the lattice.

22. A method for creating a cold fusion reaction in a palladium lattice electrode comprising:

formulating a heavy water electrolytic solution with a molality of .1 to .5 lithium deuteroxide having a 99.5% purity of Li^6 to provide deuterons and lithons as diffusing particles;

immersing the palladium lattice in the electrolytic solution;

introducing an electric field of 10 to 50 mA/cm^2 perpendicular to a <1,1,0> direction in the crystals of the lattice to load the lattice;

loading the lattice to a stoichiometry of .7 to 1 with deuterons from the electrolytic solution creating a β phase in the resulting palladium deuteride lattice;

heating the electrolytic solution to a temperature exceeding a plurality of transmission resonance temperatures for the diffusing particles; and,

controlling current in the electrode and temperature of the electrolytic solution to control the fusion reaction.

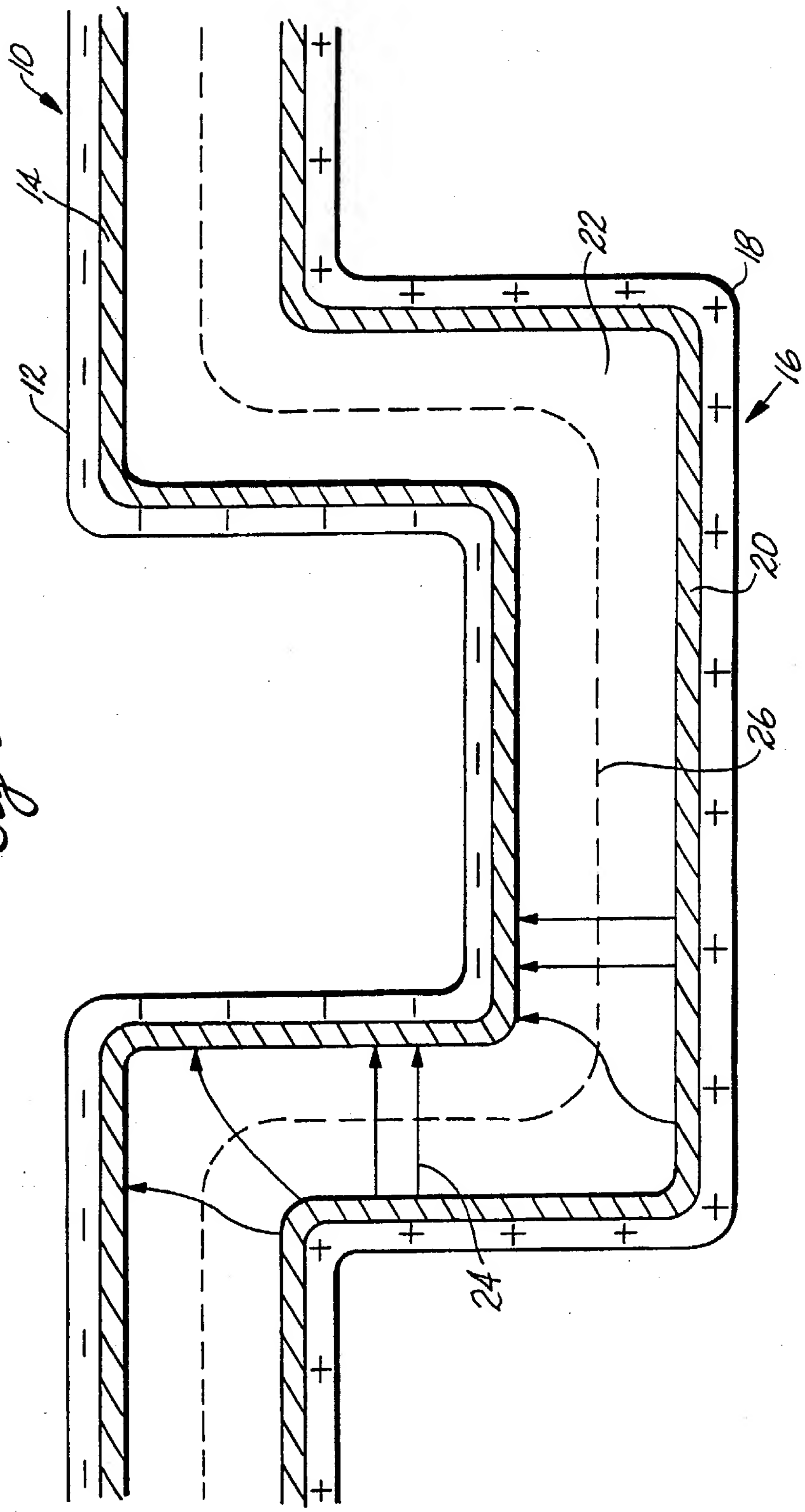


Fig. 1

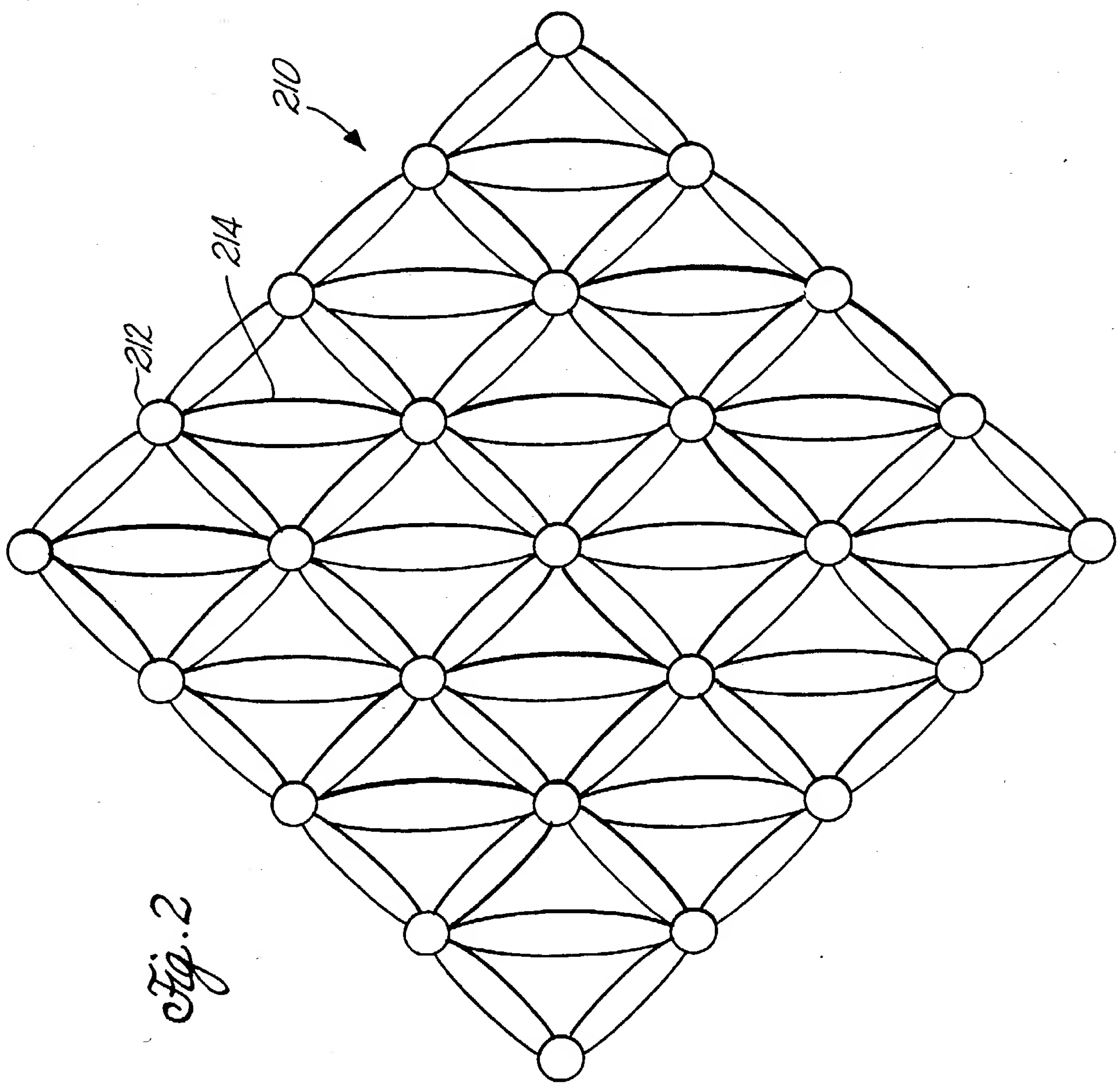


Fig. 2

Fig. 3

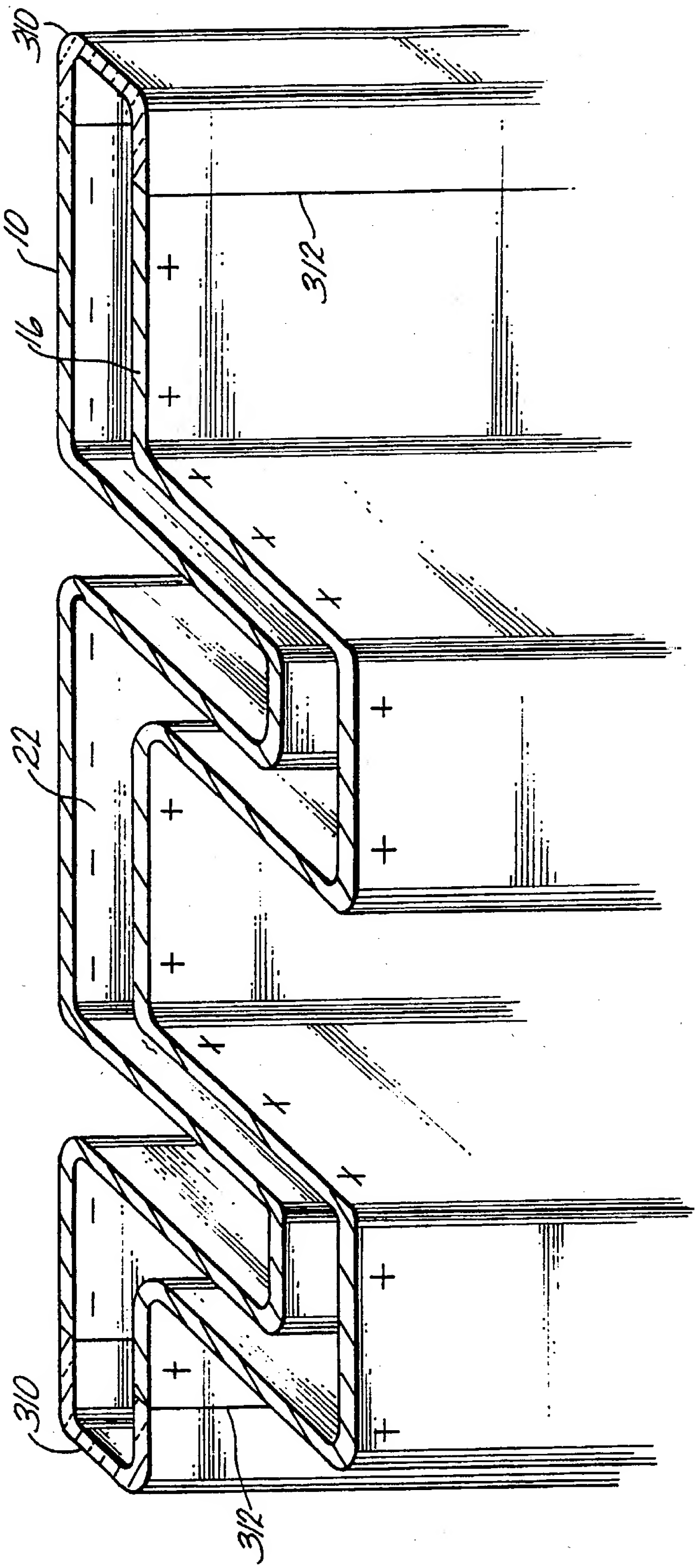
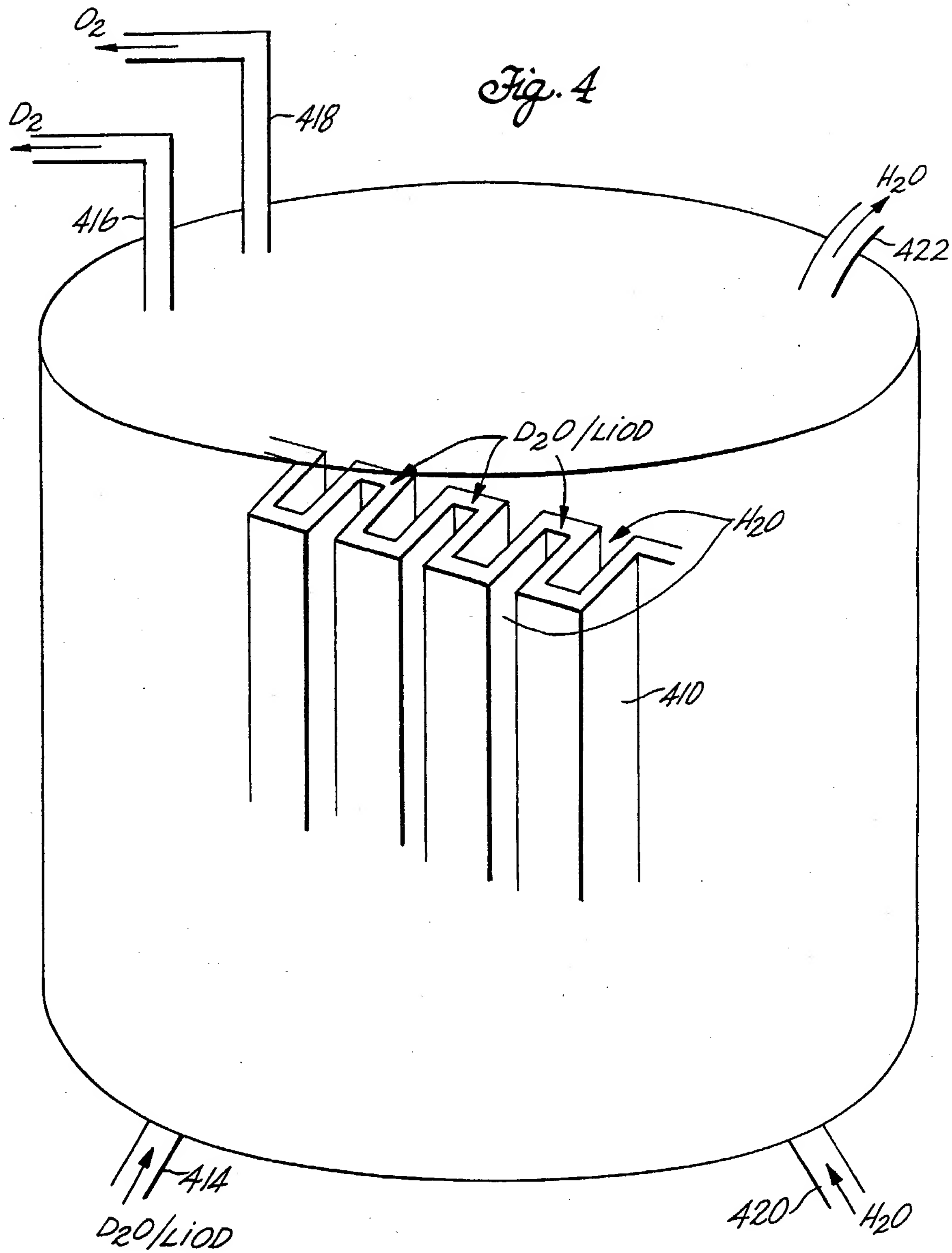
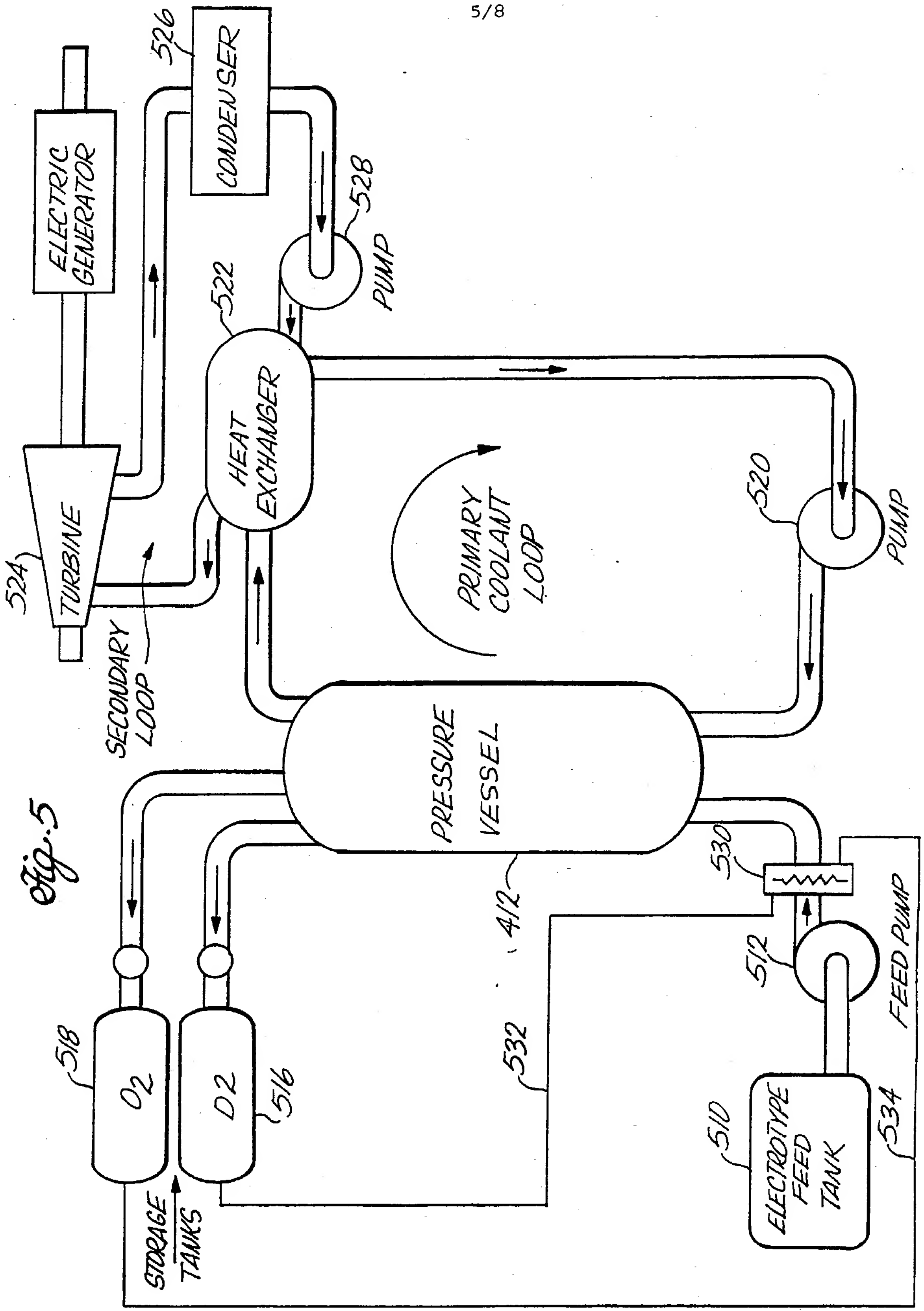


Fig. 4

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CONDENSER
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528
PUMP
522
HEAT EXCHANGER
TURBINE
524
SECONDARY LOOP
PRIMARY COOLANT LOOP
520
PUMP
PRESSURE VESSEL
412
530
512
FEED PUMP
518
O2
D2
516
STORAGE TANKS
532
510
ELECTROTYPE FEED TANK
534

Fig. 5

Fig. 6

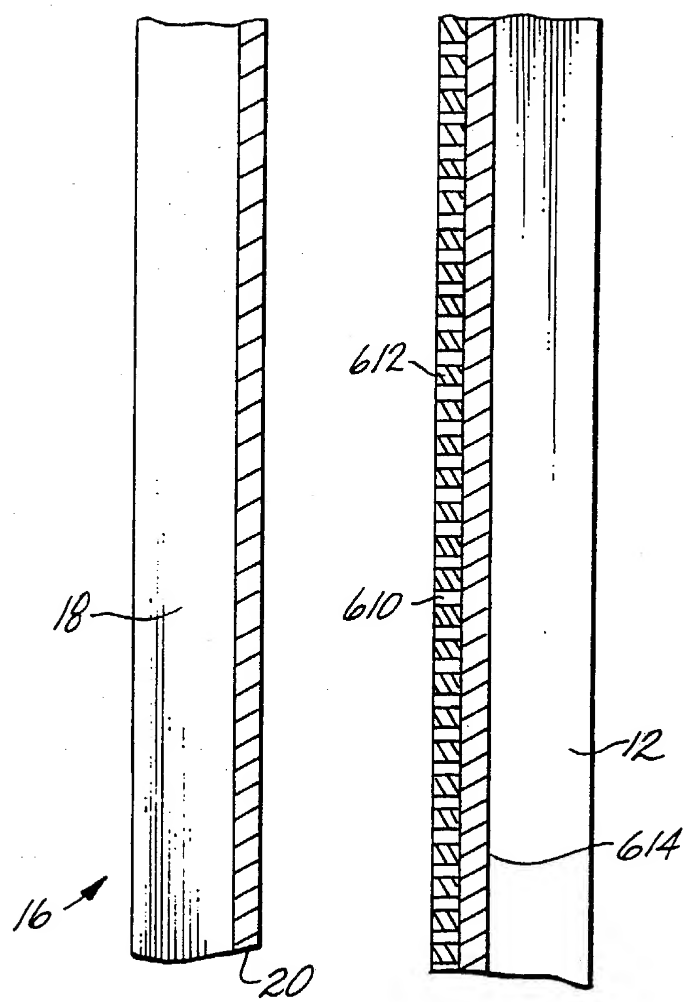
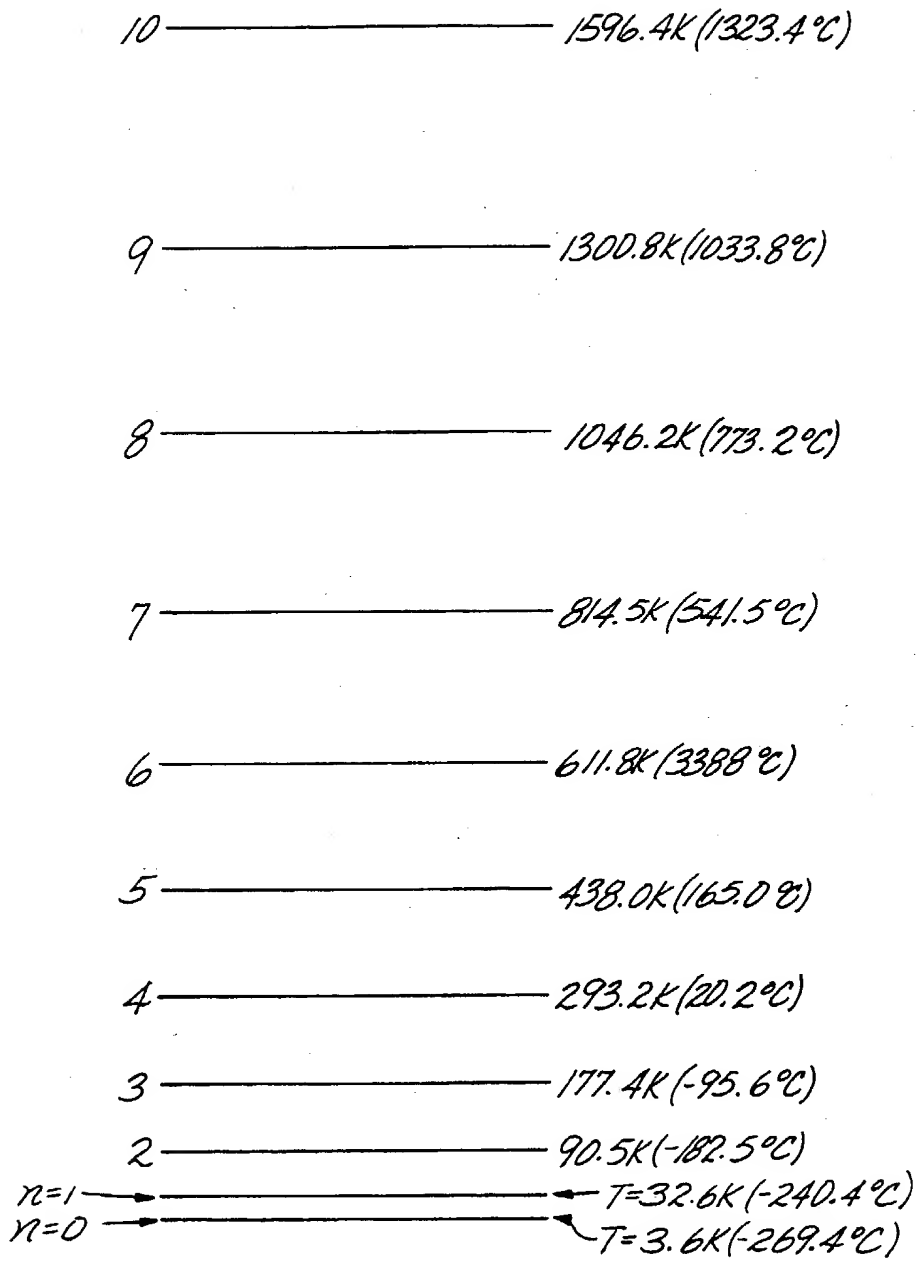


Fig.7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6
611.8K(3388°C)
5
438.0K(165.0°C)
4
293.2K(20.2°C)
3
177.4K(-95.6°C)
2
90.5K(-182.5°C)
n=1
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n=0
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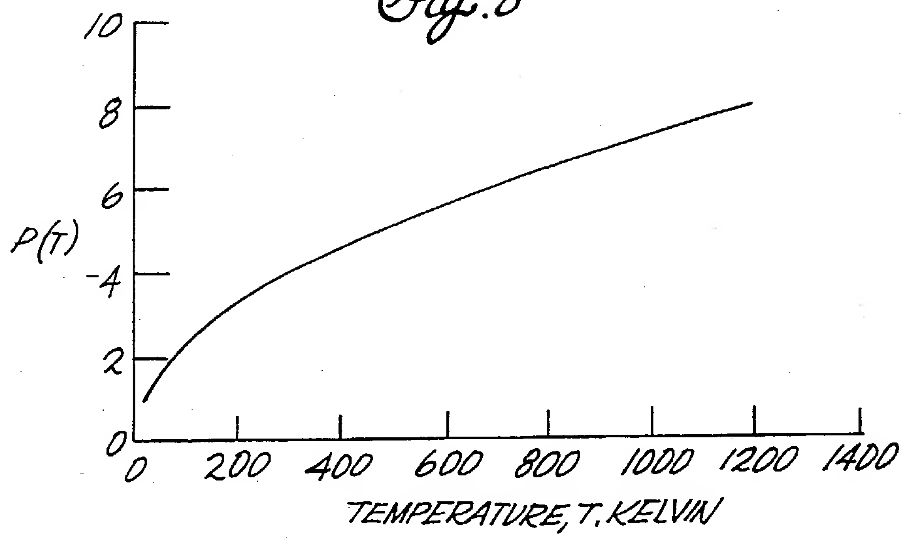
Fig.8


10
8
6
P(T)
-4
2
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200
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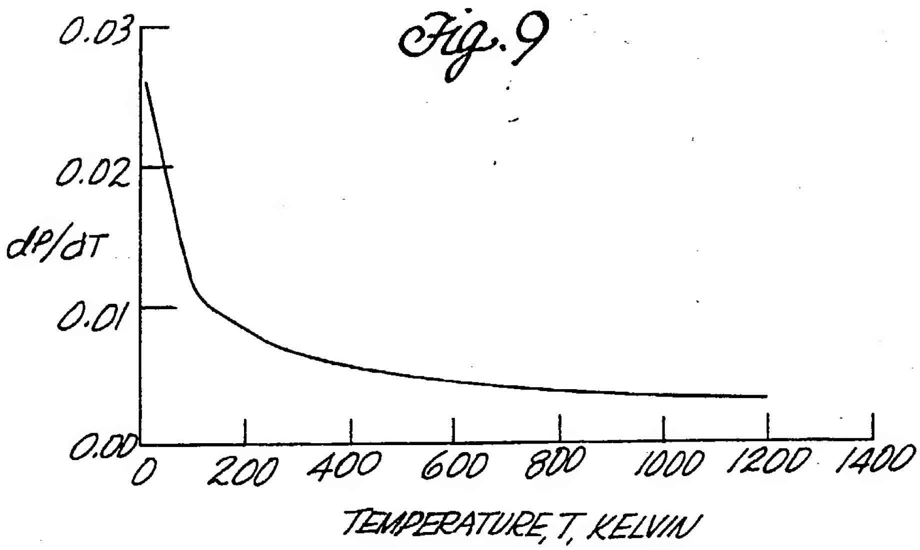
600
800
1000
1200
1400
TEMPERATURE, T. KELVIN

Fig.9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1200
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TEMPERATURE, T, KELVIN

INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/07073

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (5): G21B 1/00
U.S.CL.: 376/100

II. FIELDS SEARCHED

Minimum Documentation Searched

Classification System	Classification Symbols
U.S.	376/100, 146, 114, 115 423/248, 645, 647.7 420/900, 463, 464, 465 204/129, 290R, 290F, 291, 292, 293, DIG. 8

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched

III. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
Y	Electroanalytical Chemistry, Volume 261, No. 2A, page 301-308, Parsons et al., April 1989.	1-22
Y	"The Palladium Hydrogen System", Academic Press 1967, page 1-180, Lewis; Figure 3.3.	2,3,6,12,15
Y	"The Kinetics of Hydrogen Absorption-Desorption by Metal", Pergamon Press 1981, page 329-343, Pick; page 341, Paragraph 2.	2,9,15,22
Y	US, A, 4,663,006 (YAO ET AL) 05 May 1987, Column 10, line s 54-57; abstract.	18
Y	US, A, 4,373,176 (FINKELSTEIN ET AL) 08 February 1983; Column 1, lines 44-51.	21
Y	US, A, 3,455,845 (WICKE ET AL) 15 July 1969; Column 1, lines 47-58; column 2, lines 31-42.	5,6,10
Y	"Determination of the Hydrogen Content of Palladium and Palladium Alloys from Measurements of Electrode Potential and Electrical Resistance", Pergamon Press 1963, Volume 10, page 237-246, Barton et al; page 239, Paragraph 5.	10

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
03 APRIL 1991	29 APR 1991
International Searching Authority	Signature of Authorized Officer
ISA/US	DANIEL WASIL

International Application No. PCT/US90/07073

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers ..... because they relate to subject matter [1] not required to be searched by this Authority, namely:

2. ☐ Claim numbers ...., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [1], specifically:

3. ☐ Claim numbers__________, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

See attachment

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☒ No protest accompanied the payment of additional search fees.

Continuation of PCT/ISA/210 item VI
"Observations where unity of invention is lacking"

I. Apparatus for producing heat energy; (claims 1-14).

II. Method of producing power; (claims 15-21).

III. Method of creating a cold fusion reaction; (claim 22).

The claims of these groups are directed to different inventions which are not so linked as to form a single general inventive concept. The inventions are not linked in operation and perform completely different operations. Note PCT Rule 13 and 37 CFR 1.475.

Within group I there is lack of unity under PCT Rule 13 between the following independent and distinct species :

Ia. The embodiment having a polycrystalline cladding; (claims 1-11, 13, 14).

Ib. The embodiment having dielectric strips bonded intermediate single crystals; (claims 1-4, 7-14).

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, 14 with indication, where appropriate, of the relevant passages 17	Relevant to Claim No 18
L	Nature, volume 344, page 401-405, 29 March 1990, Salamon et al., cited as casting doubt on inducing nuclear fusion in a catalyst by forcing hydrogen isotopes therein.	1-22
L	ORNL/FTR-3341, page 1-17, 31 July 1989, Cooke; Cited as casting doubt on inducing nuclear fusion in a catalyst by forcing hydrogen isotopes therein, see page 3-5.	1-22